The use of Meteorological Data to Improve Contrail Detection in Thermal Imagery over Ireland.

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Summary

Aircraft induced contrails have been found to have a net warming influence on the climate system, with strong regional dependence. Persistent linear contrails are detectable in 1 Km thermal imagery and, using an automated Contrail Detection Algorithm (CDA), can be identified on the basis of their different properties at the 11 and 12 μm wavelengths. The algorithm's ability to distinguish contrails from other linear features depends on the sensitivity of its tuning parameters. In order to keep the number of false identifications low, the algorithm imposes strict limits on contrail size, linearity and intensity. This paper investigates whether including additional information (i.e. meteorological data) within the CDA may allow for these criteria to be less rigorous, thus increasing the contrail-detection rate, without increasing the false alarm rate.

1 Introduction

Contrails are artificial linear ice-clouds that form in the wake of jet aircraft, when the hot and moist exhaust gases mix with much colder ambient air. Under suitable meteorological conditions, contrails can persist for several hours and trigger additional cirrus cloud formation. Previous studies into the climate impact of linear contrails have found that contrails produce a small but significant net warming effect on the climate system (Stuber et al., 2006). The IPCC's fourth assessment report (2007) assigned a global Radiative Forcing (RF) of +0.010 Wm^{-2}, while Stuber et al. (2006) quote a regional value over a high traffic location in the UK of +0.23 Wm^{2} – one order of magnitude higher than the global estimated value. However, the climate impact of contrail-cirrus may be between 2 to10 times larger than this. The high regional dependence of this effect suggests that for countries such as Ireland, who have a high density of air-traffic, these effects could be even greater than is outlined in the latest IPCC report. Lee et al. (2009) present an updated estimate of global linear contrail RF of +0.0118 Wm^{2} for 2005 based on updated air-traffic operations data. No best-estimate for the RF of induced-cirrus-cloudiness is presently available, although Lee et al. (2009) postulate that it could be 0.033Wm^{2}, although with large uncertainties and based on a very low level of scientific understanding.

Furthermore, aviation demand is reportedly increasing, with the total number of aircraft expected to double in the next twenty years, and annual aviation fuel use to increase by 3.9% (Whitelegg, 2006). From 2002-2008, overflights in Irish air-space increased substantially, such that the maximum number of overflights in 2008 was double that of the 2002 minimum (Figure 1).

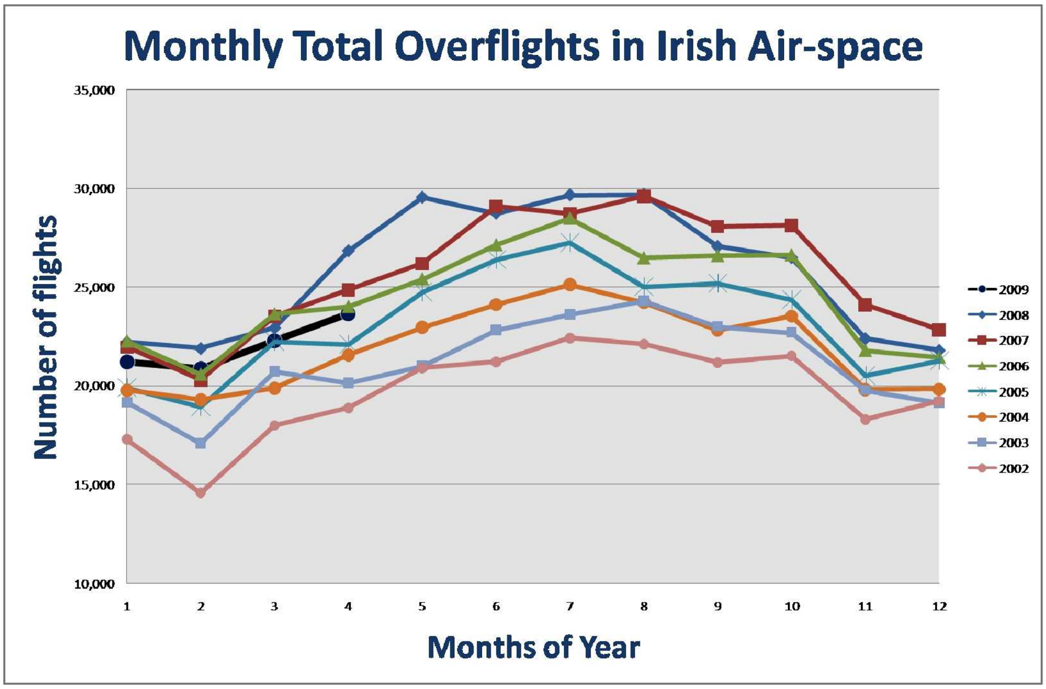

Figure 1 Monthly total overflights through Irish air-space.

Most of the North Atlantic flight Tracks (NATs), are located directly to the west of Ireland, with a large number of high altitude (above 24,000ft) overflights crossing Ireland every day peaking during the early (eastbound traffic) and late (westbound traffic) morning. Overflights increased from 2002-2008 but values for 2009 (January to April) are consistently less than for other years (Figure 1).

Persistent spreading contrails can induce additional cirrus cloud formation. Palle and Butler (2001) observed a 15% increase in Irish cloud cover and a corresponding 20% drop in annual sunshine hours at four ground stations from 1881-1998. What proportion, if any, of this cloud cover increase can be attributed to increasing aviation activity over Ireland? To what extent are Irish skies and climate modified by high altitude overflights? In order to answer these questions, an objective evaluation of contrail coverage trends over Ireland is needed. Satellite imagery is the only source of data that allows the objective production of a cloud and contrail climatology over the course of a whole year. Presently, the Contrail Detection Algorithm (CDA) that operates on the dual thermal channels of A/ATSR or AVHRR imagery is deliberately tuned to have a low false alarm rate, but this results in a low contrail detection efficiency also. This paper investigates the possibility of including meteorological information within the CDA to improve its detection efficiency without increasing its false alarm rate.

2 Aims and Objectives

Both meteorological data (with air-traffic data) and satellite imagery can be used independently to investigate contrail occurrence and persistence; but this research aims to evaluate whether integrating upper atmospheric pressure, humidity and temperature data (from radiosondes), in conjunction with known meteorological contrail formation conditions, as part of the decision-making criteria within the CDA, (originally developed by Mannstein et al. (1999) at DLR) improves contrail detection without increasing false alarms.

3 Contrail Detection from Satellites

The low brightness temperature of contrails in the thermal infrared and their characteristic linear shape allow them to be detected by passive remote sensing methods. Linear contrails are visible in the 11 and 12 μm channels of AVHRR and AATSR, but due to their higher transmissivity at the shorter thermal wavelength, they show up more clearly in 11-12 μm temperature difference images. Mannstein et al. (1999) proposed a fully automated algorithm for evaluating contrail coverage in AVHRR 11 and 12 μm thermal imagery, and the same method is applicable to A/ATSR imagery.

The CDA has two main inputs; the 11-12 μm temperature difference (TD) image and the 12 μm image. Normalisation and filtering techniques are applied to these images (Mannstein et al., 1999), and linear features which are potentially contrails extracted. In order to identify which of these objects are contrails, the algorithm subjects each to a series of threshold 'checks' to reject those which are definitely not contrails. Unfortunately, a lot of actual contrails are also eliminated by this approach. The contrail-checks examine the size, linearity and intensity of each object, and the thresholds set within the algorithm for each of these parameters are tuneable. Optimising the CDA to limit the misdetection rate is an iterative process. Using this technique, Mannstein et al. (1999) successfully identified approximately 30 to 50% of those contrails visibly recognisable in the original TD image, keeping the false alarm rate at just 0.1%.

The CDA has been applied to AATSR imagery of Ireland and the surrounding coastal waters, as shown in Figure 2a for 17/03/2009 at 11:18UTC. Figure 2b shows the 11-12 μm temperature difference for this region, and Figure 2c the linear features extracted by the CDA prior to checking. Figure 2d shows the features identified by the CDA as contrails, with a coverage in this area of 2.061%. The CDA was run with default (stringent) threshold criteria, therefore this value of ~2% contrail-coverage, although high for the area, is nonetheless considered to be a conservative estimate of the contrail-coverage in this scene. Based upon preliminary results, this value of 2% from the imagery is very unusual. Initial evaluations for contrail-coverage (when present) generally range from 0.1 to 0.6%; which is more consistent with the value of 0.5% obtained by Mannstein et al. (1999) for central Europe in 1996 (which was regarded as a conservative estimate).

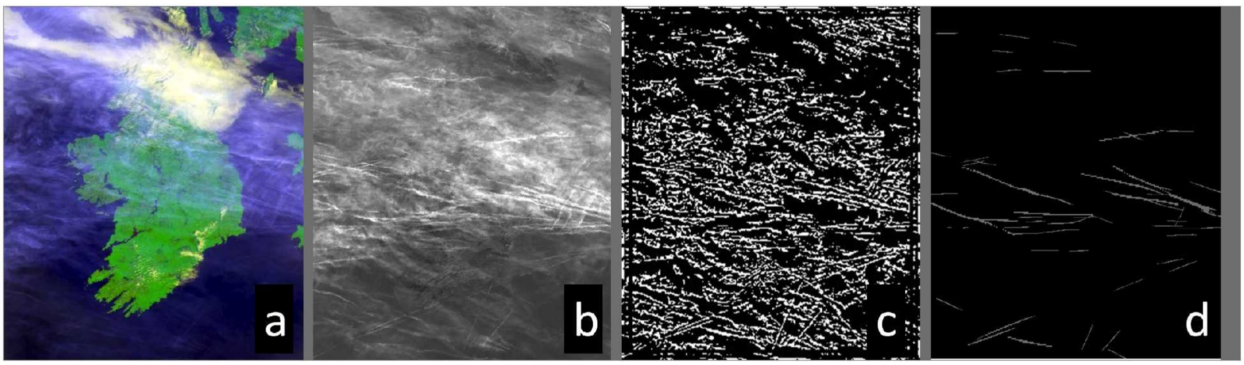

Figure 2: AATSR image for 17/03/2009 at 11:18UTC. a) True colour image, b) 11-12 μm temperature difference image, c) extracted linear features and d) identified contrails (~2% coverage).

The timing of the image shown in Figure 2 coincides with one of the heaviest periods of aircraft traffic crossing Ireland, predominantly in a westward direction from continental Europe and the UK. If conditions have been conducive for contrail formation for some time, it is possible that the cirrus coverage seen across the centre of Ireland is contrail-induced-cirrus.

Radiosonde measurements of ambient atmospheric pressure, temperature and humidity allow for this hypothesis to be further explored.

4 Combining Meteorological Data with CDA

Aircraft contrails, or 'condensation-trails', form as a result of the mixing of hot and humid exhaust air with much colder ambient air below a critical temperature threshold, as defined by the 'Schmidt-Appleman' criterion (Figure 3) (see Schumann, 1996 for more details).

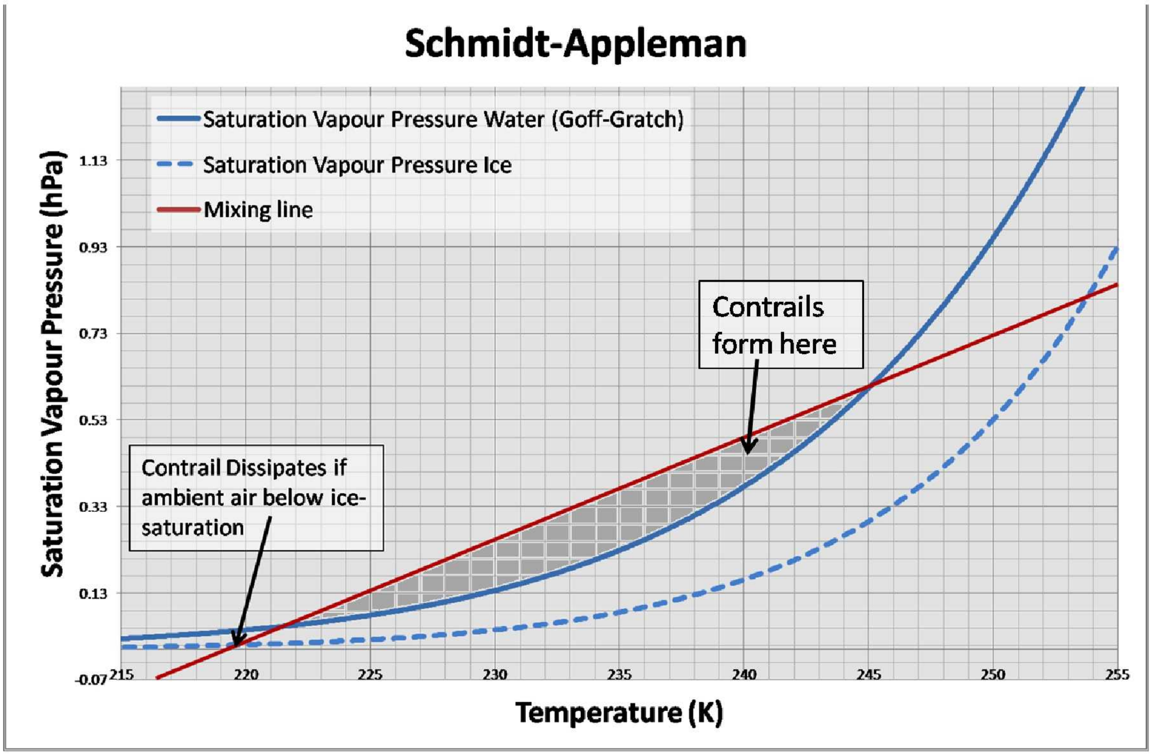

Figure 3 Schmidt-Appleman criterion for contrail formation. The red line represents the state of the exhaust air as it mixes with environmental air. Where this line crosses the saturation vapour pressure curve for water, a contrail will from. If ambient air is saturated with respect to ice, contrails will persist.

The critical temperature for contrail formation is dependent upon ambient pressure, relative humidity and the aircraft's contrail factor, with the critical temperature calculated for each atmospheric layer (Schumann, 1996) from radiosonde data. Figure 4 shows a radiosonde ascent from Valentia at 11:15UTC coincident with the AATSR overpass discussed above, with the contrail-susceptible layer of the upper atmosphere shown to occur centred around the 200hPa pressure level (which corresponds to approximately 35,000ft – a typical cruising altitude for transatlantic flights). In this instance, the radiosonde's path might not take it directly through one of the contrails shown on the image in Figure 2 however it does indicate the potential for upper atmospheric conditions to support contrail formation at this time.

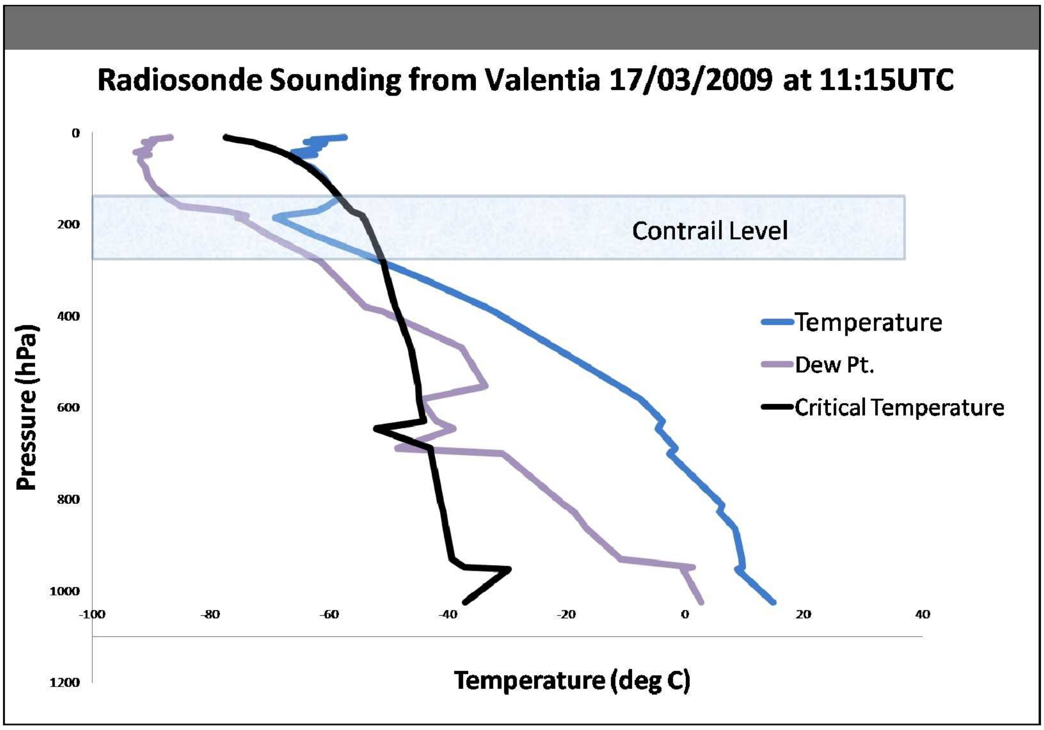

Figure 4 Radiosonde sounding indicating contrail susceptible atmospheric layers for the same date and approximate time as the AATSR imagery in Figure 2.

If the atmospheric relative humidity is above ice-saturation, contrails that form will persist under these conditions, as hypothesised for the image in Figure 2. Several studies (Schumann 1996; Steufer et al., 2005; Stuber et al., 2006; Rädel and Shine, 2007) have successfully predicted contrail persistence using these criteria with reasonable accuracy. Based on these results, a modification of Mannstein's CDA is proposed to include an additional check that would only identify an 'object' as a contrail if the Schmidt-Appleman criterion was met and the atmospheric relative humidity was ice-supersaturated. If the meteorological conditions for contrails to form and persist are not met then the 'object' on the image is unlikely to be a contrail. By this means more non-contrail objects can be excluded, thus allowing the other contrail-identification checks to be more inclusive, without increasing the false alarm rate. A flow diagram outlining our approach is below (Figure 5).

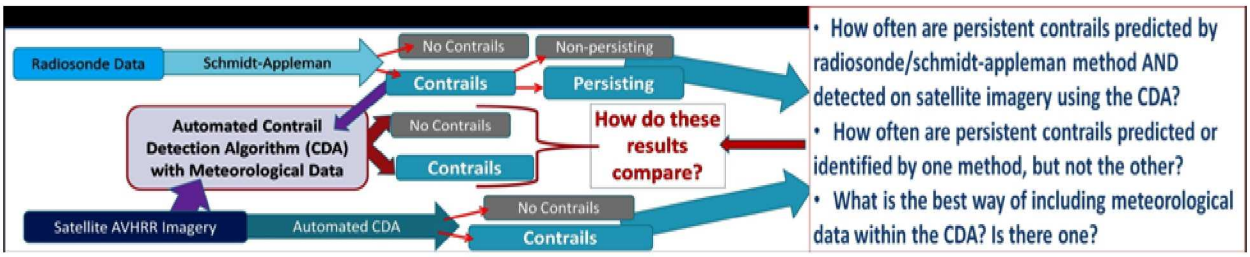

Figure 5 Outline of approach to modify CDA with meteorological data.

The effect of this modification will be ascertained using an interactive software tool developed by researchers at NASA, and described by Minnis et al. (2005) which allows the user to manually add missed contrails and remove false alarms. The software tracks these 'corrections' to gauge the efficiency of the algorithm. By comparing the output from the 'pure' CDA and the 'meteorological' CDA the impact of including meteorological data on the overall detection efficiency will be assessed.

5 Discussion and Conclusion

As demonstrated by the sample image shown here (Figure 2), there are occasions when the meteorological conditions in the upper atmosphere over Ireland support unusually high contrail formation and persistence, with eventual dispersion into high level cirrus cloud. As shown by Figure 4 the atmospheric conditions are conducive to contrail formation at an altitude commensurate with transatlantic aircraft, supporting the results of the CDA. On the date shown in the image here, clear skies over Ireland would have allowed the high level contrail coverage to be observed from the ground, but it is not currently known how prevalent such extreme contrail coverage incidents are, or whether their number and duration is increasing as the amount of aircraft has increased. This research aims to use satellite imagery to gain a greater insight into the long term trends in contrail-coverage over Ireland, and subsequently to provide an estimation of their RF contribution and the regional effects of air-traffic on the Irish climate.

6 Acknowledgements

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